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Validation of NEMA NU4-2008 Scatter Fraction estimation with ^{18}F and ^{68}Ga for the ARGUS small-animal PET scanner



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Abstract– The scatter fraction (SF) in PET data represents the fraction of coincidence events in which at least one of the two emitted photons have been scattered before being detected. It is usually estimated as the ratio of scattered events to total number of coincidences, when the number of random counts is negligible (less than 1% of true rates). SF provides a measurement of the relative sensitivity of the scanner to scattered radiation. It depends on object size, density and location inside the field of view, as well as on detector size, type of detector crystal and energy window. The performance evaluation guideline for small-animal PET NEMA (National Electrical Manufacturers Association) NU4-2008 proposes the estimation of the SF for three test phantoms made in proportion to the most widely used small animals in the laboratory: mouse, rat and monkey. The method estimates the different coincidence types in sinogram profiles from an off-centered line source inserted in these phantoms. We benchmark the procedure proposed by NEMA to estimate SF with ^{18}F and also with ^{68}Ga , a radionuclide with larger positron range. Real data acquired with the ARGUS small-animal PET scanner (SEDECAL, Madrid, Spain) as well as simulations of the same scanner with peneloPET are used. The results show that, though SF should be practically the same with both ^{18}F and ^{68}Ga isotopes (and indeed our simulations indicate this) NEMA SF estimations with ^{68}Ga acquisitions are higher. This is due to the fact that ^{68}Ga positron range affects on the width of the line source profiles. Suggestions to modify the protocol to obtain similar SF estimations when using isotopes with larger positron range than ^{18}F are made.

I. INTRODUCTION

THE scatter fraction (SF) in PET data represents the fraction of coincidence events in which at least one of the two emitted photons have been scattered before being detected. It provides a measurement of the relative sensitivity of the scanner to scattered radiation. It is usually estimated as the ratio of scattered events to total number of coincidences, when

the number of random counts is negligible (less than 1% of true rates).

The National Electrical Manufacturers Association (NEMA) has published the standard (NEMA NU 4-2008) for performance measurements for small animal PET scanner [1]. Standardized procedures, including those for scatter fraction measurements, are specified in this publication for evaluating the performance of small-animal PET scanners. This SF is used to estimate the scanner noise equivalent count rates (NEC). These measurements are based on the work described in [2].

In this work we benchmark the procedure proposed by NEMA NU4-2008 [1] to estimate SF with ^{18}F and also with ^{68}Ga , a radionuclide with larger positron range. The main advantage of ^{68}Ga over ^{18}F is that it can be obtained on-site, since is extracted from a gallium-68 generator, and a cyclotron is not necessary.

For this study, real data acquired with the ARGUS small-animal PET scanner [3] (SEDECAL, Madrid, Spain) as well as simulations of the same scanner with peneloPET [4] are used.

II. MATERIALS & METHODS

A. Scanner description

The system employed (high-resolution small-animal Argus PET/CT scanner [3], (SEDECAL, Madrid, Spain)) integrates a fully functional PET and CT scanner.



Fig. 1. Argus PET/CT scanner.

The PET system has two block-rings with 13×13 crystal arrays of LYSO and GSO with a transaxial FOV of 68 mm.

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B. Real and simulated data

In order to evaluate the estimation of SF with the protocol proposed by NEMA NU4-2008 [1], real data acquired with the ARGUS small-animal PET scanner (SEDECAL, Madrid, Spain) [3] as well as simulations of the same scanner with peneloPET (based on Penelope Monte Carlo code) [4], were used. The results were obtained using the mouse phantom and an energy window from 100 to 700 keV. The activity in the line source inserted in the phantom (mouse size) was low to ensure that the number of random counts was negligible (less than 1% of true rates). Simulated data were obtained with and without scanner shielding and animal bed materials.

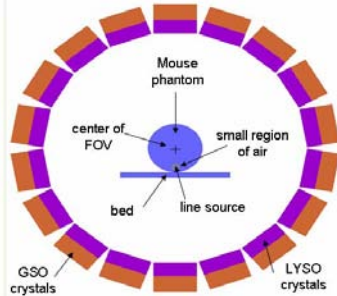


Fig. 2. Argus PET/CT and phantom diagram.

An accurate simulation of the positron range, taking into account the small region of air between the line source tube and the polyethylene phantom, was necessary in order to reproduce the width of line source profiles for both radionuclides.

C. SF estimation (NEMA NU4-2008)

According to NEMA data processing and analysis ([1], section 4), data was sorted into a sinogram using the single slice rebinning (SSRB) technique (175 radial bins, 128 angular bins and 61 slices). Background from intrinsic radioactivity of lutetium was subtracted only for real data (simulations did not included crystal intrinsic radioactivity).

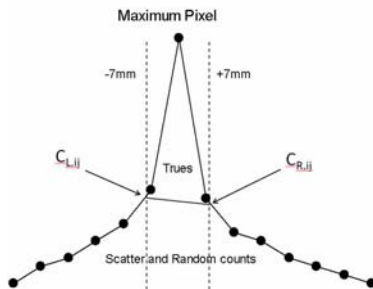


Fig. 3. Integration of background counts inside and outside the 14 mm strip, as recommended in NEMA.

After sinogram alignment, a sum projection was performed such that a pixel in the sum projection represents the sum of the pixels in each angular projection having the same radial offset. The resulting profiles had 175 bins of 0.3885 mm/bin. A 14 mm wide strip at the center of the sinogram was drawn to separate scatter from true coincidences.

III. RESULTS

A. Experimental results

In Fig. 4, ^{18}F and ^{68}Ga radial profiles of sinograms are compared for real acquisitions. We can see a wider line source profile for ^{68}Ga .

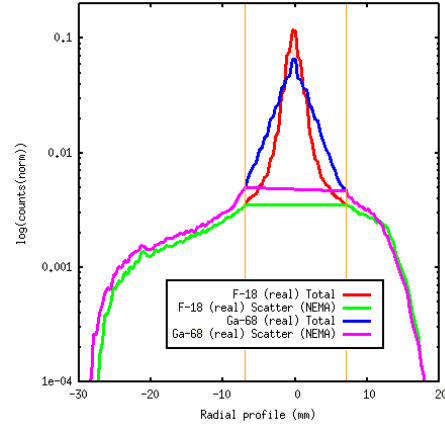


Fig. 4. ^{18}F and ^{68}Ga radial profiles for real acquisitions.

Profiles have been normalized dividing by the total counts of the profile (logarithmic scale). The two vertical lines show the edges of a 14 mm wide strip.

With the standard NEMA procedure, this increased width will lead to a spurious estimation of the fraction of scattered counts, because contributions coming from the profile tail of the true counts contaminate the “scatter region” defined by NEMA due to the effect of positron range. As we can see from the results of the simulations, (Table I), the SF should be the same for both isotopes.

TABLE I. SCATTER FRACTION VALUES FOR REAL DATA

Isotope	SF (%) (NEMA)
^{18}F	28
^{68}Ga	35

B. Analysis using simulations

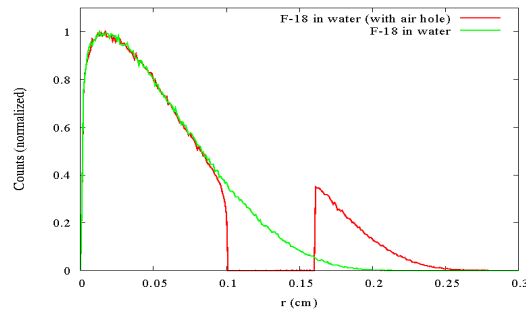


Fig. 5.1. Radial profiles of positron annihilation events in water and in water plus the observed air gap, for ^{18}F .

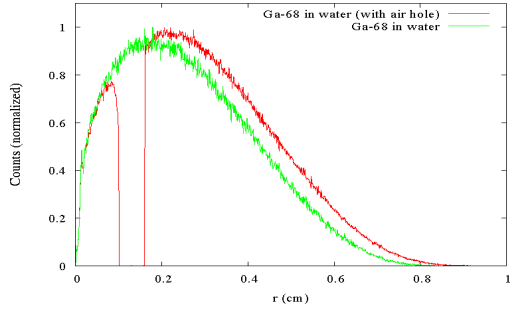


Fig. 5.2. Radial profiles of positron annihilation events in water and in water plus the observed air gap, for ^{68}Ga .

Fig. 5.1 and 5.2 show the radial profiles of positron range in water and in water plus the actually observed air gap in

between the capillary tube and the phantom. These profiles were used in the different simulations.

Fig. 6.1 and 6.2 show a comparison between real and simulated data (with and without scanner shields and two different positron range profiles (Fig. 5)) for ^{18}F (Fig. 6.1) and ^{68}Ga (Fig. 6.2) respectively. Differences between simulations (with shields and realistic positron range) and real data are probably due to additional shields not considered. We did not find these differences in the rPET scanner as it is shown in [4].

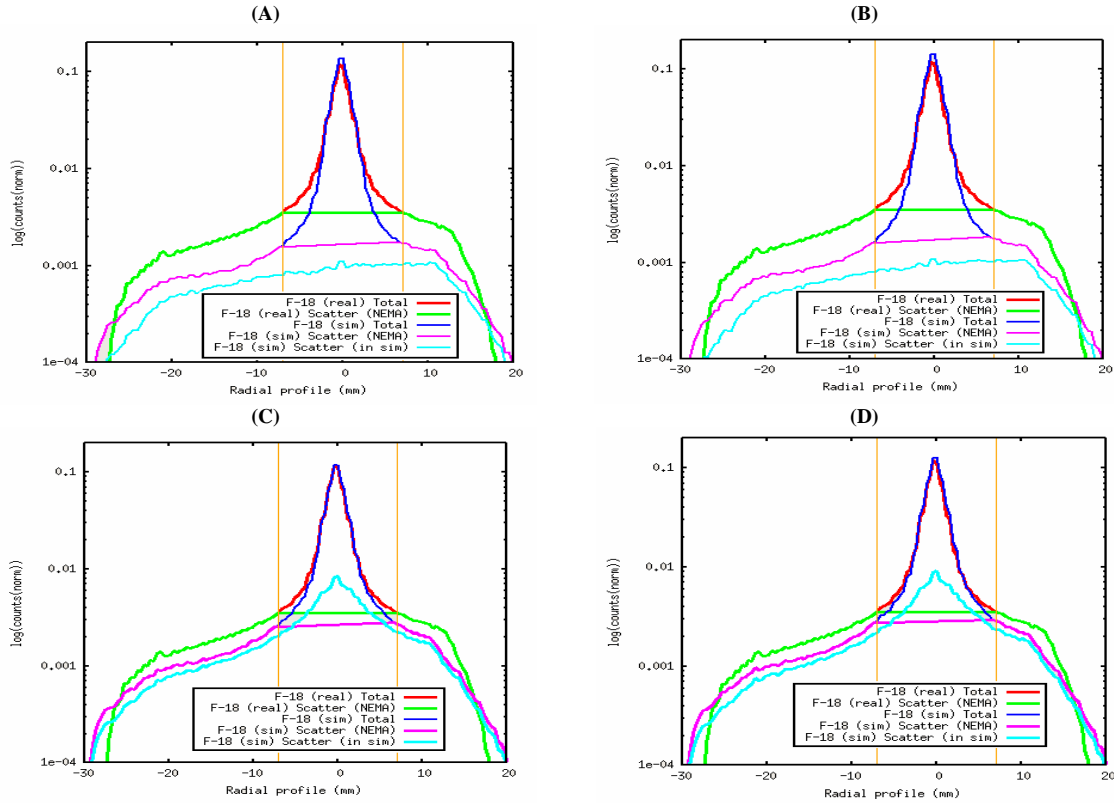


Fig. 6.1. ^{18}F radial profiles for real acquisitions compared to different simulations: (A) Scanner without shields. Positron range in water. (B) Scanner without shields. Positron range in water plus the thin air layer. (C) Scanner with shields. Positron range in water. (D) Scanner with shields. Positron range in water plus the thin air layer.

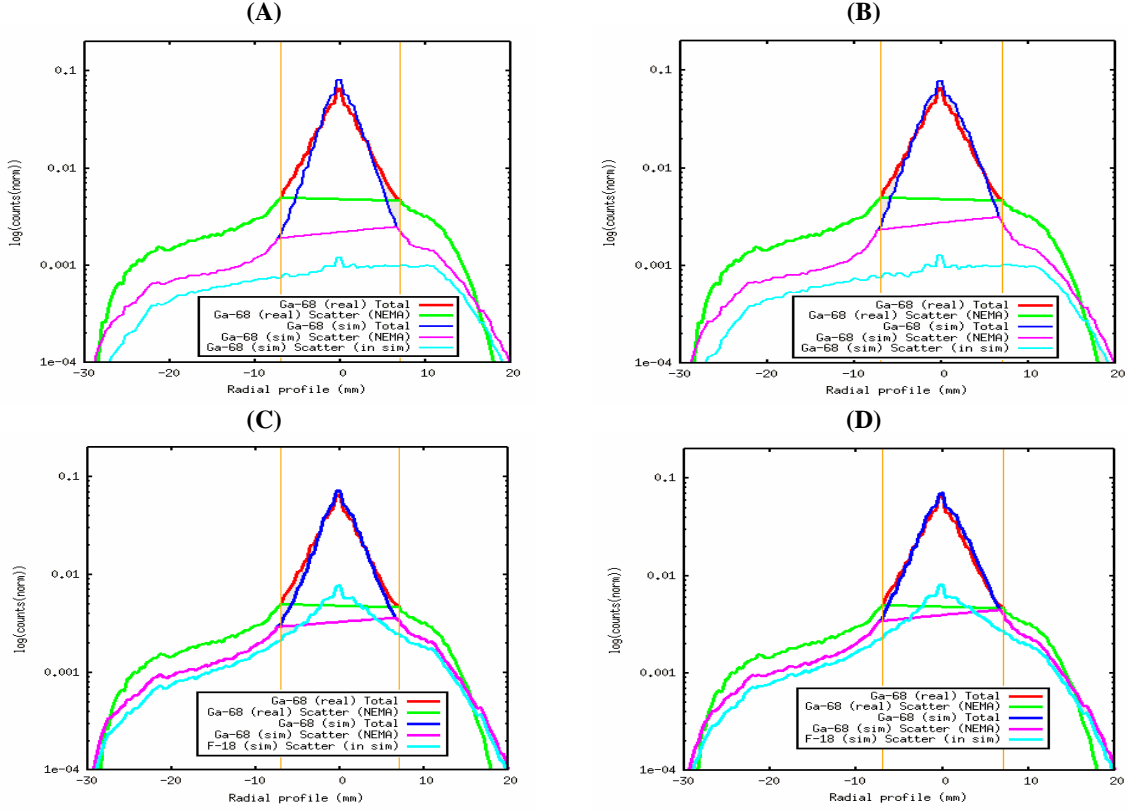


Fig. 6.2. ^{68}Ga radial profiles for real acquisitions compared to different simulations: (A) Scanner without shields. Positron range in water. (B) Scanner without shields. Positron range in water plus the thin air layer. (C) Scanner with shields. Positron range in water. (D) Scanner with shields. Positron range in water plus the thin air layer.

SF for simulated data obtained from the NEMA protocol and the actual values for both radionuclides are presented in Table II.

TABLE II. SCATTER FRACTION VALUES FOR SIMULATED DATA (SIMULATIONS WITH THE MORE REALISTIC POSITRON RANGE)

Isotope	Shields	SF (%) in simulations	
		Actual value	NEMA
^{18}F	No	11	13
^{68}Ga	No	11	18
^{18}F	Yes	29	21
^{68}Ga	Yes	29	26

C. Suggestion to improve the NEMA protocol

Table I and Table II show that the NEMA protocol overestimates the SF for ^{68}Ga due to its larger positron range. In order to use the NEMA protocol with a different isotope, we propose in this work to the positron range contribution to the radial profiles (Fig. 7).

The results of the NEMA SF values with and without positron correction for both isotopes are shown in Table III. We can see that for ^{18}F there are not differences in SF values with and without the correction but SF for ^{68}Ga provides the same value than ^{18}F after positron range correction.

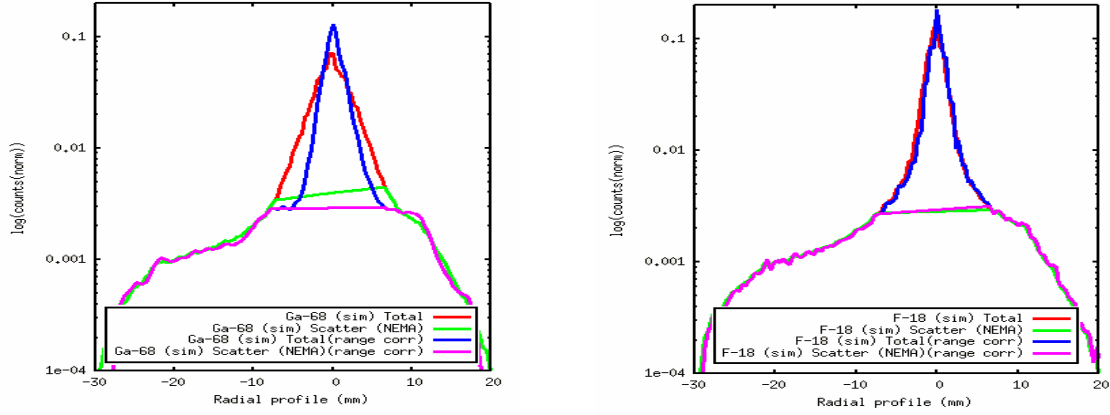


Fig. 7. ^{18}F and ^{68}Ga radial profiles and SF values with and without positron range correction

TABLE III. SCATTER FRACTION VALUES FOR SIMULATED DATA WITH AND WITHOUT POSITRON RANGE CORRECTION

Isotope	Range correction	SF (%) (NEMA)
^{68}Ga	No	26
	Yes	21
^{18}F	No	21
	Yes	21

IV. CONCLUSIONS

Positron range corrections are necessary if isotopes with significantly large positron range (as ^{68}Ga) are used to estimate the SF using the NEMA protocol.

From our simulations, we have observed that, when shields are considered, the NEMA protocol results in a slight underestimation of the SF.

Scatters in the shields seem to be one of the main reasons for the underestimation of the SF in the NEMA procedure. In order to reproduce adequately the experimental data, simulations should model shields accurately.

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